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THE BEHAVIOR OF A METALITE PLATE
WHEN SUBJECTED TO UNIFORMLY DISTRIBUTED LOADS
ACTING IN THE PLANE OF THE PLATE

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" /
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1949

A Thesis Submitted to the Faculty of the Graduate School
in Partial Fulfillment of the Requirements for the
Degree of Master of Science

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PREFACE

As far as the writer knows biaxial, uniformly distributed edge loading of simply supported sandwich plates has not been widely achieved in testing programs. It is intended that the method, with results, enumerated herein is not a realization of the goal but progress in that direction.

The writer takes this opportunity to acknowledge the supervision and advice of his thesis advisor, Professor Joseph A. Wise of the Institute of Technology, University of Minnesota, the assistance of Second Lieutenants Rens Knudsen and Paul Kjoelseth, Norwegian Air Force in the laboratory work, and Mr. W. A. Pitman and others of the Chance Vought Aircraft Division of the United Aircraft Corporation.

It was a revelation at the time but progress in that

The editor takes this opportunity to acknowledge

the supervisor and adviser at his thesis advisor, Dr. Joseph A. Rice of the Institute of Technology, University of Minnesota, the maintenance of sound chemical and laboratory work, and Dr. W. A. Brown and others at the Division of the United States

• *not a priority*

ABSTRACT

The design of an arrangement for applying uniformly distributed biaxial loads to a plate when the plate edges are simply supported is presented; the behavior of a sandwich plate (Metalite) when it was subjected to this type of load and edge conditions is presented. The method of transformed sections is utilized to predict the plate critical load for the sandwich plate (Metalite); a comparison is made between the value predicted by this method and that predicted from laboratory testing with the loading arrangement. Principal strains and principal stresses at selected points on the surface of the plate are presented; deflections of these selected points also are included.

DEFINITION OF PROBLEM

By means of a testing apparatus and procedure it was desired to observe the behavior of a flat Metalite plate with the edges of the plate simply supported when the plate was subjected to uniformly distributed loads acting biaxially in the plane of the plate. From these observations it was intended that the plate critical load could be established for the edge and load conditions specified. Thus, the problem was two fold; (1) to obtain the desired edge conditions for the plate; (2) to observe the behavior of the plate.

APPENDIX

The design of the experiment for studying uniformly distributed plastic limits is a plate when the plate edges are simply supported in horizontally. The reaction at the supports (vertical) when it is subjected to this type of load and edge conditions is presented. The values of horizontal reactions is related to vertical the plate vertical load for the supports plate (vertical). A comparison is made between the value predicted by this method and that predicted from laboratory testing with the loading arrangement. Principal stresses and principal stresses at various points on the surface of the plate are presented. Calculations of stress related points are also included. The results of the tests are presented in the following table.

RESULTS OF TESTS

By means of a testing apparatus and procedure it was desired to observe the behavior of a thin elastic plate with the edges of the plate simply supported when the plate was subjected to uniformly distributed loads acting normally in two planes at the plate. Two stress distributions it was intended that the plate exhibit have could be established for the edge and inner conditions specified. Thus, the problem was two fold: (1) to obtain the desired edge conditions for the plate; (2) to observe the behavior of the plate.

LIMITATIONS OF PROBLEM

(a) For the test specimen

It was assumed that the test specimen was flat prior to test. This condition did not prevail because the plate had an initial curvature in each of the two edge directions; in magnitude it was in the order of one-tenth of an inch at the center of the plate. It was assumed that the test specimen was representative of any Metalite plate fabricated to the same over-all and component parts dimensions as the plate tested.

(b) For the testing apparatus

As the apparatus originally was designed the biaxial loads applied to the plate were to be distributed uniformly along the edges of the plate through a system of toothed blocks. The teeth were incorporated in the blocks to relieve the edge restrictions to plate contraction imposed by the action of biaxial loading transmitted by a continuous surface. In the testing of the plate it was necessary to sacrifice the principal of the toothed blocks in order to hold the plate in position when it was subjected to loads. The modification of the testing apparatus which was required to hold the plate in position also restricted the available amount of edge rotation of the plate; the restriction made it impossible to apply sufficient load to realize experimentally the plate critical load. The assumption that the edges of the plate

DESCRIPTION OF FIGURES

(a) For the first specimen

It was assumed that the first specimen was flat prior

to test. This condition did not prevail because the plate

had an initial curvature in some of the two edge directions

in magnitude it was in the order of one-tenth of an inch

at the center of the plate. It was assumed that the first

specimen was representative of any similar plate

fabricated in the same way and subjected to the

conditions as the plate tested.

(b) For the second specimen

As the specimen originally was designed the plate

loads applied to the plate were to be distributed uniformly

it along the edges of the plate through a system of four

at angles. The loads were transmitted in the direction

to follow the edge conditions in plate construction

imposed by the edges of plates leading to the

up a continuous surface. In the testing of the plate

it was necessary to maintain the position of the plate

since in order to hold the plate in position when it was

subjected to loads. The modification of the testing

apparatus which was required to hold the plate in position

also required the addition of edge rollers at

the plates the position was as indicated in figure

wellhead and as tested experimentally the plate

original load. The assumption that the edges of the plate

were simply supported was not realized exactly; the center lines of edge rotations were in the mid-plane of the plate removed approximately two and thirteen-sixteenths inches from the edges.

CONCLUSIONS

(1) That for edge and load conditions as specified (simply supported and uniformly distributed, respectively) the plate critical load for a Metalite plate of the size and dimensions tested as determined from an analysis of the deflection data is ten thousand two hundred pounds (two hundred ninety pounds per linear inch).

(2) That the plate critical load as predicted by the method of transformed section is eight thousand five hundred and eighty-five pounds (two hundred forty-five pounds per linear inch).

(3) That the difference between these predicted plate critical loads is due in part to the type of analysis of the deflection data (assuming that the deflection is infinite at the plate critical load).

(4) That duplications of this testing should be performed on similar plates to establish the plate critical load.

(5) That the testing apparatus should be modified further or in a different manner in order that the edge conditions assumed and sought may be more nearly realized.

into single specimens and not loaded exactly the same
 lines of edge resistance were in the mid-plane of the
 plate tested approximately two and a half times
 longer than the others.

Conclusions

(1) That for any one load conditions as specified
 (which is supported with uniformly distributed, respectively)
 the plate exhibits load for a definite plate at the same
 and dimensions tested as determined from the analysis of
 the deflection data is ten thousand two hundred pounds
 (two hundred thirty pounds per linear inch).

(2) That the plate exhibits load as produced by the
 method of transverse section is eight thousand five
 hundred and thirty-five pounds (two hundred thirty-five
 pounds per linear inch).

(3) That the difference between these produced
 plate exhibits load is due in part to the type of analysis
 of the deflection data assuming that the deflection is
 uniform at the same exhibits load.

(4) That application of this testing should be per-
 formed on similar plates to establish the plate exhibits
 load.

(5) That the testing apparatus should be modified
 further as it is different because in order that the same
 conditions assumed and tested may be more nearly realized.

INTRODUCTION

To explain the fabrication of Metalite, the following is quoted from an article "Experiences With Sandwich Materials in Air Frames" by H. B. Gibbons and E. MacDonough of Chance Vought Aircraft presented at a symposium on "The Theory and Practice of Sandwich Construction in Aircraft" at the sixteenth annual meeting of the Institute of the Aeronautical Sciences in New York City during 26-29 January 1948:

"The manufacture of Metalite is essentially a molding operation which involves a series of relatively simple processes. The sheet metal parts are first cut to shape, then thoroughly cleaned, masked for spraying, and sprayed with Cycleweld adhesive. They are then cured for one-half hour at 325 degrees Fahrenheit. The end grain core is produced by gluing a number of balsa planks into bolts about two feet by four feet in cross-section and by cutting slices slightly greater than the required core thickness from these bolts with a band saw. To form the required panel size, the slices are further edge-glued together and trimmed. The panel is sanded to the desired thickness on a drum sander and routed where necessary for internal doublers and splice plates. The wood core is then sized with a very light application of a radically different type of resin and no further adhesive applied. The secondary adhesive is applied to the areas of the metal

1. Introduction

The purpose of this report is to provide a detailed description of the following

is based on the results of the following

Materials in Air by H. H. Nichols and E. H. Nichols

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parts that are coated with Cycleweld. The metal parts are then assembled with the wood core on a mold of the required contour. The assembly is covered with a light rubber blanket, which is sealed to the mold, and cured in an autoclave for one hour at 230 degrees Fahrenheit and sixty pounds per square inch."

TEST EQUIPMENT

- (1) Olsen compression-load testing machine.
(provided the vertical component of the biaxial loads)
- (2) Load distributing arrangement (see Appendix A).
(also included provision for horizontal component of biaxial loads)
- (3) SR-4 Baldwin Southwark Strain Indicator.
- (4) Test specimen (Metalite plate) with properly attached strain gages (rosettes).
- (5) Ames deflection dials.

TEST PROCEDURE

- (1) Calibrate the tension rods in a tensile testing machine for a load versus strain curve.
(established a means for determining the horizontal load applied to the test specimen)
- (2) Align the frame of the load distributing apparatus on supports on the bed of the Olsen compression-load testing machine.

Twenty three are coated with Urethane. The other twelve are
from specimens with the wood core in a state of low reaction
response. The assembly is finished with a light primer
coat, which is sealed to the wall, and coated in the
interior for use as a 400-gram laboratory seal.

- (1) Obtain comprehensive testing results.
(2) Provide the various components of the clinical
exam.
(3) and detailed assessment (see Appendix A).
(4) Obtain feedback from the clinical component
of clinical exam.
(5) Obtain feedback from the clinical component.
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(8) Obtain feedback from the clinical component.

- (1) The first step in the process of determining the lead is to identify the lead. This is done by comparing the lead with the lead in the lead book. If the lead is not in the lead book, it is a new lead. If it is in the lead book, it is a known lead. The lead is then classified as either a new lead or a known lead. The lead is then classified as either a new lead or a known lead. The lead is then classified as either a new lead or a known lead.

- (3) Install the test specimen, load distributing bars and blocks in the frame in a manner such that the applied loads will act in the plane of the plate (assuming the plate is flat).
- (4) Wire all strain gages to the selector box.
(facilitated the observing and recording of strain indicator readings)
- (5) Secure the mounts for the Ames dials to the frame and attach the dials to the mounts.
- (6) Record the no-load strain indicator reading of all the strain gages and zero the Ames dials.
- (7) Apply biaxial loads in desired increments, record the strain gage and Ames dial readings at each increment.

TEST SPECIMEN

Type Metalite plate.

Size: Thirty-five inches square.

Core: Nine pounds per cubic foot balsa wood.
(tolerance of plus one-half pound, minus nothing). Thirty-six hundredths of an inch thick.

Faces: 24S-T3 Alclad aluminum alloy, grain on opposite faces parallel.
Sixteen thousandths of an inch thick.

Adhesive: Redux.

Composition: Figure 2.

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PRESENTATION OF OBSERVATIONS

The four strain gage rosettes on each face of the plate were mounted opposite each other in the following manner (Figure 3):

I	opposite V	III	opposite VII
II	opposite VI	IV	opposite VIII

In addition, on the east face of the plate rosettes II and IV were symmetrically located; a similar relationship existed between rosettes VI and VIII on the west face of the plate.

In Table I is presented the strain indicator readings reduced to a zero reading at no-load conditions. In Tables 2, 3, 4, and 5, which include the maximum and minimum strains and stresses as determined from the solution of the strain gage rosettes, the angles listed are those which are included between the line of maximum strain or stress and a horizontal axis originating at the center of the rosette. For the rosettes on the east face of the plate the angle is measured positively in a counterclockwise direction from the north end of the horizontal axis, and positively in a clockwise direction from the north end of the horizontal axis for the rosettes on the west face of the plate. This convention of sign notation and selection of references facilitates comparisons between values on opposite faces of the plate at the four locations of the rosettes.

PRESENTATION OF OBSERVATIONS

The four main data consisted on each case of the plate were measured separately each after in the following manner (Figure 1):

- I. Opposite V
- II. Opposite VI
- III. Opposite VII
- IV. Opposite VIII

In addition, on the east side of the plate opposite I and IV were respectively located a similar relation ship station between opposite VI and VII on the west side of the plate.

In Table I is presented the within instrument readings reduced to a zero reading at up-bow condition. In Table II, 0.5, 1.0 and 2.0, which indicate the mean and standard

error and standard deviation from the center of the main data station, the angles listed are those which are included between the line of maximum strain at stress and a horizontal line originating at the center of the plate. For the stations on the east side of the plate the angle is measured positively in a counter-clockwise direction from the north end of the horizontal axis, and positively in a clockwise direction from the north end of the horizontal axis for the stations on the west side of the plate. This convention of sign notation was adopted at reference facilities arrangements between values at opposite ends of the plate at the same location of the station.

In Figures 6, 7, 8, and 9 the difference in maximum principal stresses between faces at the location of each of the rosettes is shown graphically.

In Figure 10 is a graphical presentation of the variation in the direction of the maximum principal strains and stresses at each of the rosette locations.

In Table 6 is contained the amounts of plate deflection at the various increments of edge loads; the locations of the deflections with respect to the plate is shown in Figure 4; this deflection data is shown graphically in Figure 5.

DISCUSSION OF DATA

At all four of the locations on the plate at which strains were measured and the principal stresses determined, the stress on the concave side (east face) of the plate was consistently greater in magnitude than on the convex side. As the plate critical load was approached these stresses tended to become more nearly equal in magnitude (Figures 6 through 9). The plot in Figure 5 of the deflection of the center of the plate was analyzed for a best-fitting curve; several expressions were tried and a secant function selected on the assumptions that the slope of the curve should be infinite at the plate critical load (the deflection also infinite) and the curve should indicate no deflection at the origin of recorded deflections. This best-fitting secant curve was determined

In Figure 6, 7, 8, and 9 the difference in maximum principal stresses between cases at same location of each of the corners is shown graphically.

In Figure 10 is a graphical presentation of the variation in the direction of the maximum principal stress and stresses at each of the corner locations.

In Table 1 is contained the amount of plate deformation at the various increments of edge loads. The location of the maximum stress with respect to the plate is shown in Figure 11. This deflection data is shown graphically in Figure 12.

DISCUSSION OF DATA

At all four of the locations on the plate at which stresses were measured and the principal stresses determined, the stress on the convex side (out face) of the plate was consistently greater in magnitude than on the concave side. As the plate varied load was applied, these stresses tended to become more nearly equal in magnitude (Figure 13, Table 1). The data in Figure 14 of the deflection at the center of the plate was analyzed for a best-fitting curve; several equations were tried and a second function existed on the assumption that the slope of the curve would be infinite at the edge (Table 1). The deflection data indicated that the curve would be infinite at the edge (Table 1). This best-fitting second curve was determined

by the method of the least sum of the squares of the differences between theoretical and actual values of deflections. The function so determined is of the form

$$\delta_n = A q_n \secant \left(\frac{\pi}{2} q_n \right)$$

where δ_n is equal to the deflection at the n th value of load,

A is equal to a constant to be determined,

q_n is equal to the ratio of $\frac{P_n}{P_{cr}}$,

P_n is equal to the load less 1000 at the n th value of load,

P_{cr} is equal to the plate critical load less 1000. For the deflections as observed at the center of the plate, values of A equal to 0.7678 and P_{cr} equal to 9200 yields the best-fitting curve. Therefore, the plate critical load (at which the deflection is infinite) by this method of extrapolation is ten thousand two hundred pounds. At an edge load of eight thousand five hundred eighty-five pounds the deflection would be two and thirty-two hundredths inches.

by the method of the least squares of the squares of the
differences between observed and calculated values of the
functions. The function in question is of the form

$$y = a + b \cos \left(\frac{\pi}{2} x \right)$$

where y is equal to the value of the function at the point x .
It is equal to the value of the function at the point x .

It is equal to the value of the function at the point x .

$$y = a + b \cos \left(\frac{\pi}{2} x \right)$$

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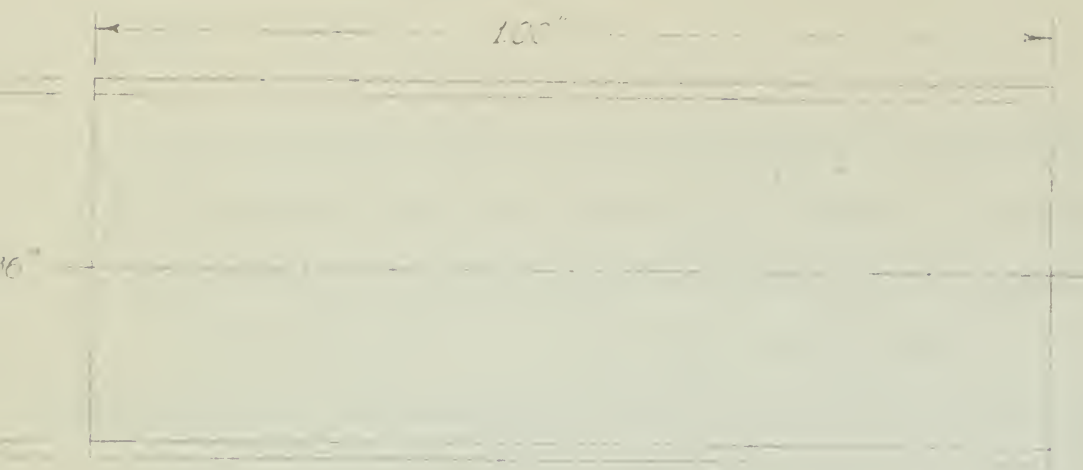
It is equal to the value of the function at the point x .

It is equal to the value of the function at the point x .

10.

FIGURE 1

TRANSFORMED SECTION



Net Area = 1600



Transformed Area = 1600



Equivalent Section

ANALYTICAL CONSIDERATION

For a rectangular, simply supported plate subjected to biaxial uniformly distributed forces the critical forces, as determined by assuming the plate deflects in the form of a double sine series and by equating the internal and external energy, are:¹

$$P_x m^2 b^2 + P_y n^2 a^2 = \frac{t^3}{12} \cdot \frac{E}{1-\mu^2} \cdot \pi^2 \cdot \frac{(m^2 b^2 + n^2 a^2)^2}{a^2 b^2}$$

By the method of transformed sections, the thickness of the web in the transformed section is equal to the ratio of the moduli of elasticity of the two materials in the compound section.² If it is assumed that the modulus of elasticity for the face material is 10.3×10^6 pounds per square inch and for the core material is 0.5665×10^6 pounds per square inch,³ the ratio of the core modulus to face modulus is 0.055, which is the thickness of the web in the transformed section.

The moment of inertia of this transformed section about its center line is 0.00134553 inches⁴. The thickness of the equivalent plate is then the cube root of 12×0.00134553 or 0.254 inches (Figure 1). Substituting this value in the above equation and assuming μ equal to 0.3, P_x equal to P_y , n equal to m equal to unity, and a equal to b equal to 35, the plate critical load is two

Subscripts 1, 2, 3, refer to references.

ANALYTICAL INVESTIGATION

For a transmission, simply supported at its ends, the deflection at any point x is given by the following equation, where w is the deflection at the point x , E is the modulus of elasticity, I is the moment of inertia, P is the load, L is the length, and a and b are the distances from the supports to the load.

where w is the deflection at the point x .

$$w = \frac{Pabx}{6EI} \left(\frac{a^2 - b^2}{L} + x \right) \quad (1)$$

By the method of least squares, the deflection at the center of the beam is given by the following equation, where w_c is the deflection at the center, E is the modulus of elasticity, I is the moment of inertia, P is the load, L is the length, and a and b are the distances from the supports to the load.

The amount of deflection at this fixed end is given by the following equation, where w_e is the deflection at the end, E is the modulus of elasticity, I is the moment of inertia, P is the load, L is the length, and a and b are the distances from the supports to the load.

hundred forty-five pounds per inch or eight thousand five hundred eighty-five pounds per edge.

If, in this calculation, a value of 10×10^6 pounds per square inch had been assumed for the modulus of elasticity of the face material, the final result would have been two hundred forty pounds per inch or eight thousand four hundred pounds per edge.

RECOMMENDATIONS

(1) That the testing apparatus be modified to allow a greater amount of rotation of edges of the test plate. This can be accomplished by reducing the size of the plate positioning blocks, or increasing the space between the angle frames, or cutting plate positioning slots into the teeth of the toothed loading blocks. These possibilities are listed in order of increasing difficulty; although the third one would be most difficult, it would produce the most desirable final result.

(2) That a series of tests be conducted on similar plates to verify the results of this project and to achieve the determination of a plate critical load by laboratory testing.

(3) That tests be conducted on plates of homogeneous material with dimensions corresponding to those obtained by the method of transformed section for use in comparative analysis.

omitted forty-five pounds per inch or eight thousand five hundred fifty-five pounds per square inch. It is this relationship, a value of 10 to 100 pounds per square inch has been assumed for the reaction of elasticity of the test material. The limit remains within have been the hundred forty pounds per inch or eight thousand five hundred pounds per square inch.

DISCUSSION

(1) That the testing specimens be modified to give a greater amount of reduction of edges of the test piece. This can be accomplished by reducing the size of the plate bending device, or increasing the space between the angle beams, or cutting plate bending device into the shape of the tested bending device. These modifications are listed in order of increasing difficulty although the third one would be most difficult, it would remove the most desirable limit result.

(2) That a series of tests be conducted on similar plates to verify the results of this project and to verify the determination of a plate critical load by laboratory testing.

(3) That tests be conducted on plates of homogeneous material with dimensions corresponding to those obtained by the method of maximum bending for use in comparative tests.

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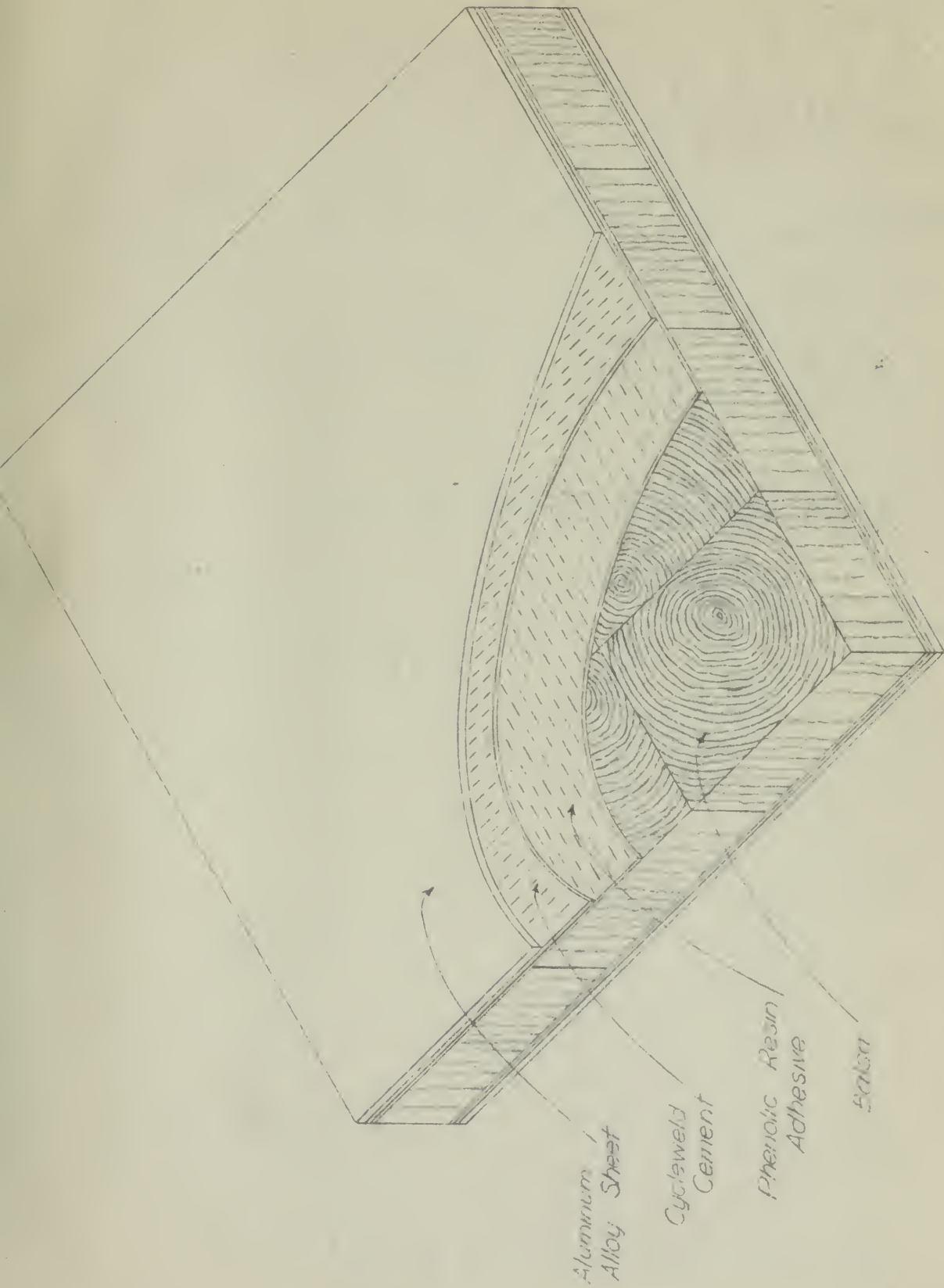
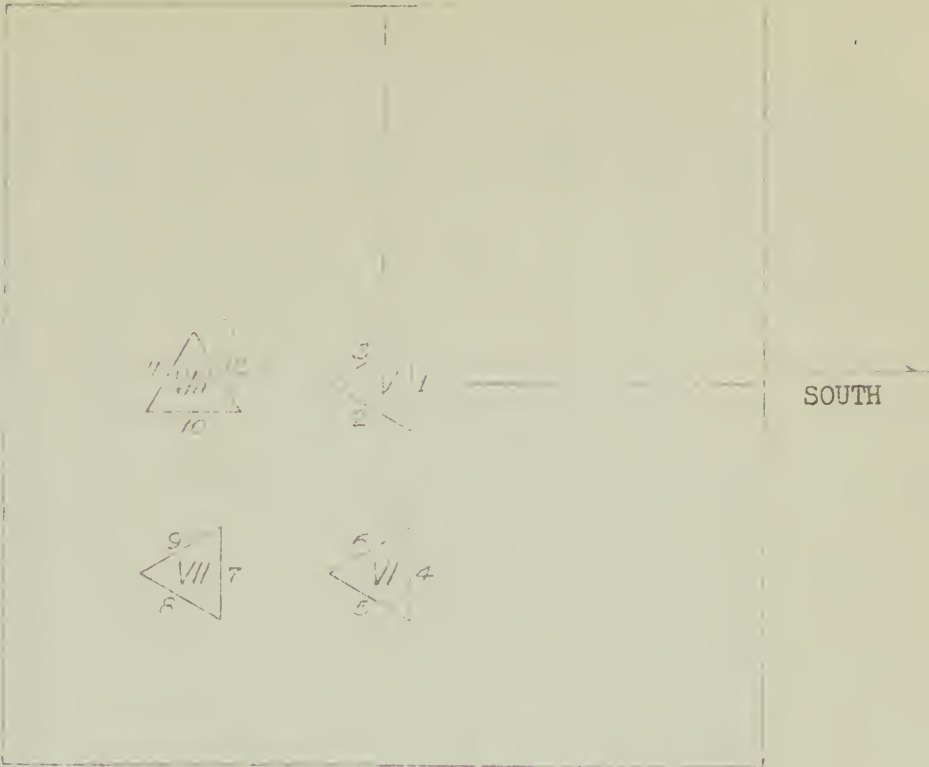
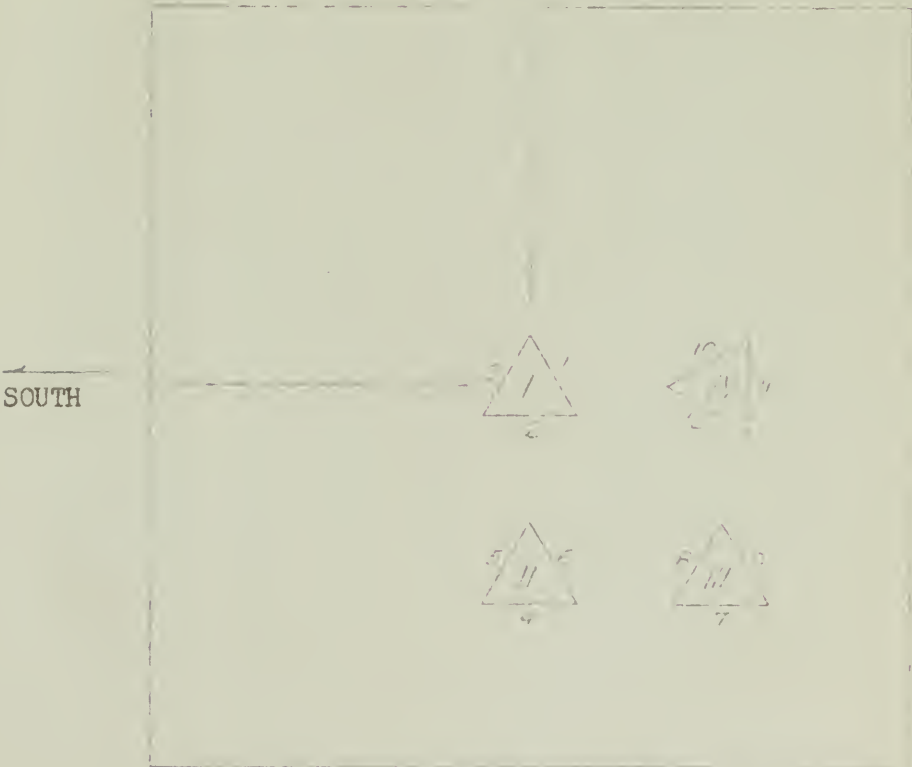


Figure 2.
Section of Metalite Sandwich

ARRANGEMENT OF STRAIN GAGES ON METALITE PLATE



WEST SIDE AS SEEN WHEN OBSERVED FROM THE WEST



EAST SIDE AS SEEN WHEN OBSERVED FROM THE EAST

TABLE 1
STRAIN GAGE DATA

EDGE LOAD	ROSETTE I			ROSETTE II			ROSETTE III			ROSETTE IV		
	GAGE 1E	GAGE 2E	GAGE 3E	GAGE 4E	GAGE 5E	GAGE 6E	GAGE 7E	GAGE 8E	GAGE 9E	GAGE 10 E	GAGE 11 E	GAGE 12 E
0000	000	000	000	000	000	000	000	000	000	000	000	000
1000	-28	-120	-40	-90	-53	-96	-95	-50	-31	-66	-23	-110
2000	-178	-229	-149	-183	-155	-200	-194	-153	-121	-162	-117	-230
3000	-338	-387	-282	-323	-280	-315	-326	-292	-191	-286	-228	-374
4000	-428	-530	-420	-453	-403	-428	-459	-458	-251	-410	-357	-526
4400	-538	-596	-473	-516	-460	-476	-520	-542	-256	-462	-417	-592
4800	-528	-640	-520	-563	-498	-508	-567	-611	-291	-510	-470	-638
5200	-647	-711	-587	-641	-553	-578	-620	-711	-309	-580	-540	-730
6000	-773	-839	-697	-785	-671	-692	-787	-921	-343	-717	-682	-885
7000	-900	-980	-779	-971	-808	-845	-1040	-1258	-387	-917	-857	-1138
EDGE LOAD	ROSETTE V			ROSETTE VI			ROSETTE VII			ROSETTE VIII		
	GAGE 1W	GAGE 2W	GAGE 3W	GAGE 4W	GAGE 5W	GAGE 6W	GAGE 7W	GAGE 8W	GAGE 9W	GAGE 10 W	GAGE 11 W	GAGE 12 W
0000	000	000	000	000	000	000	000	000	000	000	000	000
1000	-25	-9	25	-19	-10	22	-40	13	43	19	-8	-77
2000	-15	8	40	3	2	27	-24	50	-22	28	-7	-57
3000	79	65	105	82	32	57	37	80	-32	67	29	3
4000	190	166	208	176	81	105	97	140	-21	146	73	86
4400	258	223	267	226	110	137	132	177	5	197	114	136
4800	327	284	330	279	143	174	170	228	13	252	149	183
5200	420	363	420	366	192	222	220	258	50	331	212	253
6000	642	549	620	568	302	332	342	370	150	526	342	405
7000	970	822	929	912	462	508	559	550	380	874	575	634

TABLE 2

PRINCIPAL STRAINS
PRINCIPAL STRESSES
REFERENCE ANGLE
ROSETTE I

BI- :	:	:	:	:	:	:	:
AXIAL:	:	:	ANGLE :	ANGLE :	:	:	:
EDGE :	MIN :	MAX :	TO MIN :	TO MAX :	MIN :	MAX :	
LOAD :	STRAIN :	STRAIN :	STRAIN :	STRAIN :	STRESS :	STRESS :	
1000 :	-5.1 :	-120.3 :	183 25 :	93 25 :	-465 :	-1380 :	
2000 :	-138.7 :	-231.9 :	169 33 :	79 33 :	-2360 :	-3100 :	
3000 :	-275.1 :	-396.3 :	164 04 :	74 04 :	-4460 :	-5420 :	
4000 :	-388.5 :	-530.1 :	178 10 :	88 10 :	-6200 :	-7330 :	
4400 :	-464.7 :	-606.7 :	164 05 :	74 05 :	-7320 :	-8450 :	
4800 :	-485.3 :	-640.1 :	178 20 :	88 20 :	-7665 :	-8900 :	
5200 :	-576.5 :	-720.1 :	165 30 :	75 30 :	-8970 :	-10100 :	
6000 :	-687.7 :	-851.7 :	163 50 :	73 50 :	-10670 :	-11980 :	
7000 :	-769.0 :	-1003.2 :	161 39 :	71 39 :	-12120 :	-13970 :	

ROSETTE V

BI- :	:	:	:	:	:	:	:
AXIAL:	:	:	ANGLE :	ANGLE :	:	:	:
ADGE :	MIN :	MAX :	TO MIN :	TO MAX :	MIN :	MAX :	
LOAD :	STRAIN :	STRAIN :	STRAIN :	STRAIN :	STRESS :	STRESS :	
1000 :	-32.4 :	26.4 :	69 10 :	159 10 :	-277 :	189 :	
2000 :	-20.8 :	42.8 :	72 20 :	162 20 :	-90 :	414 :	
3000 :	59.6 :	106.4 :	49 55 :	139 55 :	1030 :	1412 :	
4000 :	163.7 :	212.3 :	42 57 :	132 57 :	2577 :	2960 :	
4400 :	222.5 :	276.2 :	35 38 :	125 38 :	3490 :	3880 :	
4800 :	284.0 :	343.4 :	31 40 :	121 40 :	4380 :	4850 :	
5200 :	363.0 :	439.0 :	30 00 :	120 00 :	5600 :	6205 :	
6000 :	547.6 :	659.8 :	23 30 :	113 30 :	8450 :	9335 :	
7000 :	818.9 :	995.1 :	22 15 :	112 15 :	12650 :	14060 :	

TABLE 3

PRINCIPAL STRAINS
PRINCIPAL STRESSES
REFERENCE ANGLE

ROSETTE II							
BI- :	:	:	:	:	:	:	:
AXIAL:	:	:	ANGLE :	ANGLE :	:	:	:
EDGE :	MIN :	MAX :	TO MIN :	TO MAX :	MIN :	MAX :	
LOAD :	STRAIN :	STRAIN :	STRAIN :	STRAIN :	STRESS :	STRESS :	
1000 :	-52.9 :	-113.1 :	146 42 :	56 42 :	-984 :	-1458 :	
2000 :	-153.3 :	-205.3 :	138 55 :	48 55 :	-2432 :	-2960 :	
3000 :	-279.6 :	-332.4 :	155 03 :	65 03 :	-4290 :	-4710 :	
4000 :	-399.2 :	-456.9 :	165 00 :	75 00 :	-6060 :	-6530 :	
4400 :	-450.7 :	-517.3 :	171 57 :	81 57 :	-6860 :	-7380 :	
4800 :	-482.7 :	-563.3 :	175 54 :	85 54 :	-7385 :	-8010 :	
5200 :	-576.5 :	-720.1 :	172 00 :	82 00 :	-8280 :	-9100 :	
6000 :	-646.0 :	-786.0 :	175 00 :	85 00 :	-9970 :	-11100 :	
7000 :	-775.6 :	-973.8 :	172 40 :	82 40 :	-12070 :	-13650 :	

ROSETTE VI							
BI- :	:	:	:	:	:	:	:
AXIAL:	:	:	ANGLE :	ANGLE :	:	:	:
EDGE :	MIN :	MAX :	TO MIN :	TO MAX :	MIN :	MAX :	
LOAD :	STRAIN :	STRAIN :	STRAIN :	STRAIN :	STRESS :	STRESS :	
1000 :	-27.2 :	22.5 :	66 02 :	156 02 :	-231 :	162 :	
2000 :	-6.0 :	27.4 :	59 02 :	149 02 :	25 :	290 :	
3000 :	28.2 :	85.9 :	15 00 :	105 00 :	610 :	1067 :	
4000 :	63.7 :	177.7 :	7 02 :	97 02 :	1324 :	1548 :	
4400 :	87.7 :	227.7 :	6 25 :	96 25 :	1766 :	2840 :	
4800 :	116.7 :	280.7 :	6 15 :	96 15 :	2264 :	3528 :	
5200 :	153.0 :	367.0 :	4 39 :	94 39 :	2978 :	4620 :	
6000 :	232.7 :	568.7 :	2 55 :	92 55 :	4560 :	7145 :	
7000 :	341.5 :	913.1 :	2 45 :	92 45 :	6965 :	11350 :	

TABLE 4

PRINCIPAL STRAINS
PRINCIPAL STRESSES
REFERENCE ANGLE

ROSETTE III							
BI- :	:	:	:	:	:	:	:
AXIAL:	:	:	ANGLE :	ANGLE :	:	:	:
EDGE :	MIN :	MAX :	TO MIN :	TO MAX :	MIN :	MAX :	
LOAD :	STRAIN :	STRAIN :	STRAIN :	STRAIN :	STRESS :	STRESS :	
1000 :	-20.8 :	-96.6 :	8 22 :	98 22 :	-676 :	-1162 :	
2000 :	-113.8 :	-198.3 :	13 00 :	103 00 :	-1960 :	-2632 :	
3000 :	-188.7 :	-350.7 :	22 57 :	112 57 :	-3330 :	-4615 :	
4000 :	-251.0 :	-527.7 :	29 53 :	119 53 :	-4630 :	-6820 :	
4400 :	-255.3 :	-623.3 :	31 58 :	121 58 :	-5000 :	-7920 :	
4800 :	-289.7 :	-689.7 :	33 38 :	123 38 :	-5625 :	-8795 :	
5200 :	-303.2 :	-790.2 :	36 13 :	126 13 :	-6125 :	-9980 :	
6000 :	-334.5 :	-1022.7 :	36 24 :	126 24 :	-7255 :	-12720 :	
7000 :	-373.0 :	-1417.0 :	36 58 :	126 58 :	-9040 :	-17300 :	

ROSETTE VII							
BI- :	:	:	:	:	:	:	:
AXIAL:	:	:	ANGLE :	ANGLE :	:	:	:
EDGE :	MIN :	MAX :	TO MIN :	TO MAX :	MIN :	MAX :	
LOAD :	STRAIN :	STRAIN :	STRAIN :	STRAIN :	STRESS :	STRESS :	
1000 :	-43.3 :	53.9 :	79 30 :	-10 30 :	-307 :	463 :	
2000 :	-47.4 :	50.0 :	113 09 :	23 09 :	-367 :	405 :	
3000 :	-36.9 :	93.5 :	138 48 :	48 48 :	-100 :	932 :	
4000 :	-24.2 :	168.2 :	142 34 :	52 34 :	297 :	1820 :	
4400 :	-0.1 :	202.7 :	141 15 :	51 15 :	687 :	2292 :	
4800 :	8.7 :	265.3 :	142 30 :	52 30 :	998 :	3030 :	
5200 :	48.3 :	303.7 :	145 05 :	55 05 :	1578 :	3600 :	
6000 :	149.3 :	425.3 :	146 25 :	56 25 :	3135 :	5320 :	
7000 :	380.0 :	612.6 :	148 49 :	58 49 :	6370 :	8235 :	

TABLE 5

PRINCIPAL STRAINS
PRINCIPAL STRESSES
REFERENCE ANGLE

ROSETTE IV							
BI- :	:	:	:	:	:	:	:
AXIAL:	:	:	ANGLE :	ANGLE :	:	:	:
EDGE :	MIN :	MAX :	TO MIN :	TO MAX :	MIN :	MAX :	
LOAD :	STRAIN :	STRAIN :	STRAIN :	STRAIN :	STRESS :	STRESS :	
1000 :	-16.1 :	-116.5 :	164 48 :	74 48 :	-578 :	-1376 :	
2000 :	-104.1 :	-235.3 :	161 40 :	71 40 :	-1977 :	-3020 :	
3000 :	-211.2 :	-380.8 :	161 35 :	71 35 :	-3680 :	-5030 :	
4000 :	-331.4 :	-530.6 :	158 54 :	68 54 :	-5555 :	-7140 :	
4400 :	-385.5 :	-595.1 :	157 13 :	67 13 :	-6380 :	-8055 :	
4800 :	-438.1 :	-640.5 :	156 35 :	66 35 :	-7135 :	-8750 :	
5200 :	-501.2 :	-732.2 :	155 42 :	65 42 :	-8160 :	-10000 :	
6000 :	-636.3 :	-886.3 :	154 33 :	64 33 :	-10200 :	-12200 :	
7000 :	-799.9 :	-1141.5 :	155 48 :	65 48 :	-12930 :	-15650 :	

ROSETTE VIII							
BI- :	:	:	:	:	:	:	:
AXIAL:	:	:	ANGLE :	ANGLE :	:	:	:
EDGE :	MIN :	MAX :	TO MIN :	TO MAX :	MIN :	MAX :	
LOAD :	STRAIN :	STRAIN :	STRAIN :	STRAIN :	STRESS :	STRESS :	
1000 :	-79.1 :	35.1 :	63 20 :	-26 40 :	-776 :	129 :	
2000 :	-58.9 :	37.6 :	71 40 :	-18 20 :	-540 :	226 :	
3000 :	4.6 :	61.4 :	78 05 :	-11 55 :	260 :	710 :	
4000 :	56.8 :	146.6 :	94 48 :	4 48 :	1140 :	1852 :	
4400 :	99.4 :	198.6 :	97 25 :	7 25 :	1800 :	2588 :	
4800 :	137.2 :	252.2 :	99 28 :	9 28 :	2410 :	3320 :	
5200 :	195.5 :	335.1 :	99 56 :	9 56 :	3355 :	4455 :	
6000 :	316.5 :	532.1 :	99 52 :	9 52 :	5505 :	7100 :	
7000 :	497.3 :	1191.3 :	102 12 :	12 12 :	9680 :	14620 :	

TABLE 6

EDGE LOAD IN POUNDS:	DEFLECTION IN THOUSANDTHS OF AN INCH					
	A	B	C	D	E	F
1000	: 000	: 000	: 000	: 000	: 000	: 000
2000	: 12	: 14	: 16	: 39	: 42	: 51
3000	: 30	: 40	: 55	: 110	: 124	: 148
4000	: 47	: 65	: 80	: 196	: 224	: 270
4400	: 58	: 80	: 96	: 240	: 277	: 333
4800	: 66	: 92	: 111	: 280	: 323	: 387
5200	: 80	: 112	: 135	: 340	: 394	: 470
5600	: 95	: 130	: 157	: 396	: 456	: 544
6000	: 118	: 157	: 186	: 476	: 544	: 647
6200	: 132	: 175	: 205	: 523	: 598	: 707
6400	: 142	: 188	: 220	: 559	: 637	: 748
6600	: 156	: 212	: 250	: 622	: 712	: 830
7000	: 181	: 250	: 291	: ---	: 814	: 940

FIGURE 4



NORTH

EAST SIDE AS SEEN WHEN OBSERVED FROM THE EAST

FIGURE 5
PLATE DEFLECTION
VERSUS
BIAXIAL EDGE LOAD

PLATE DEFLECTION VERSUS BIAXIAL EDGE LOAD
 METALITE PLATE
 35 INCHES SQUARE
 FACE THICKNESSES 0.016
 CORE THICKNESS 0.35

DEFLECTION IN THOUSANDTHS OF AN INCH
 PLATE DEFLECTION

1200

1100

1000

900

800

700

600

500

400

300

200

100

BIAXIAL EDGE LOAD

1000

2000

3000

4000

5000
POUNDS

6000

7000

8000

9000

20

40

60

80

100

120

POUNDS

140

160

PER INCH

180

200

220

240

260

280

F

E

D

C

B

A

FIGURE 6
MAXIMUM PRINCIPAL STRESS
VERSUS
BIAXIAL EDGE LOAD

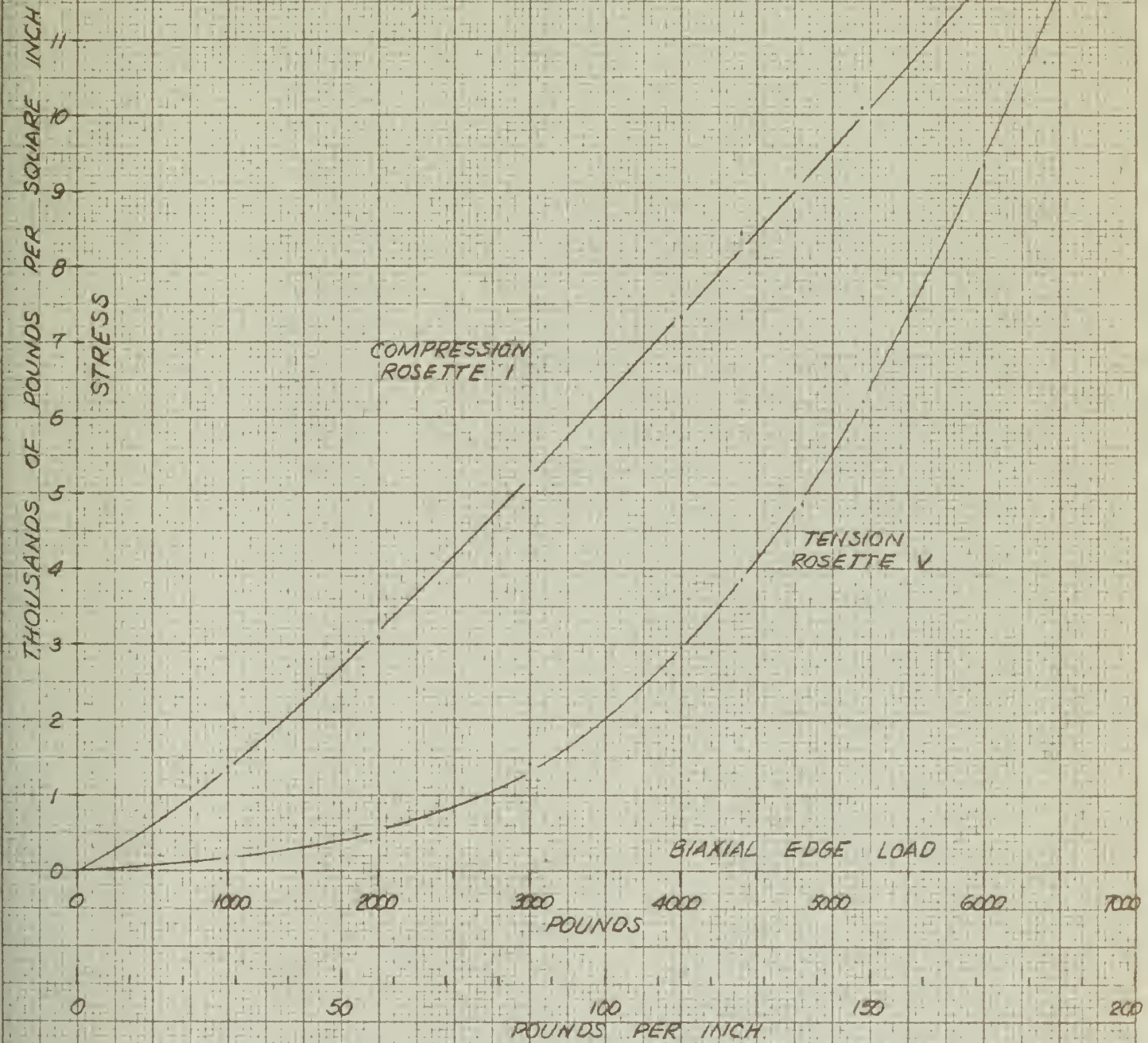
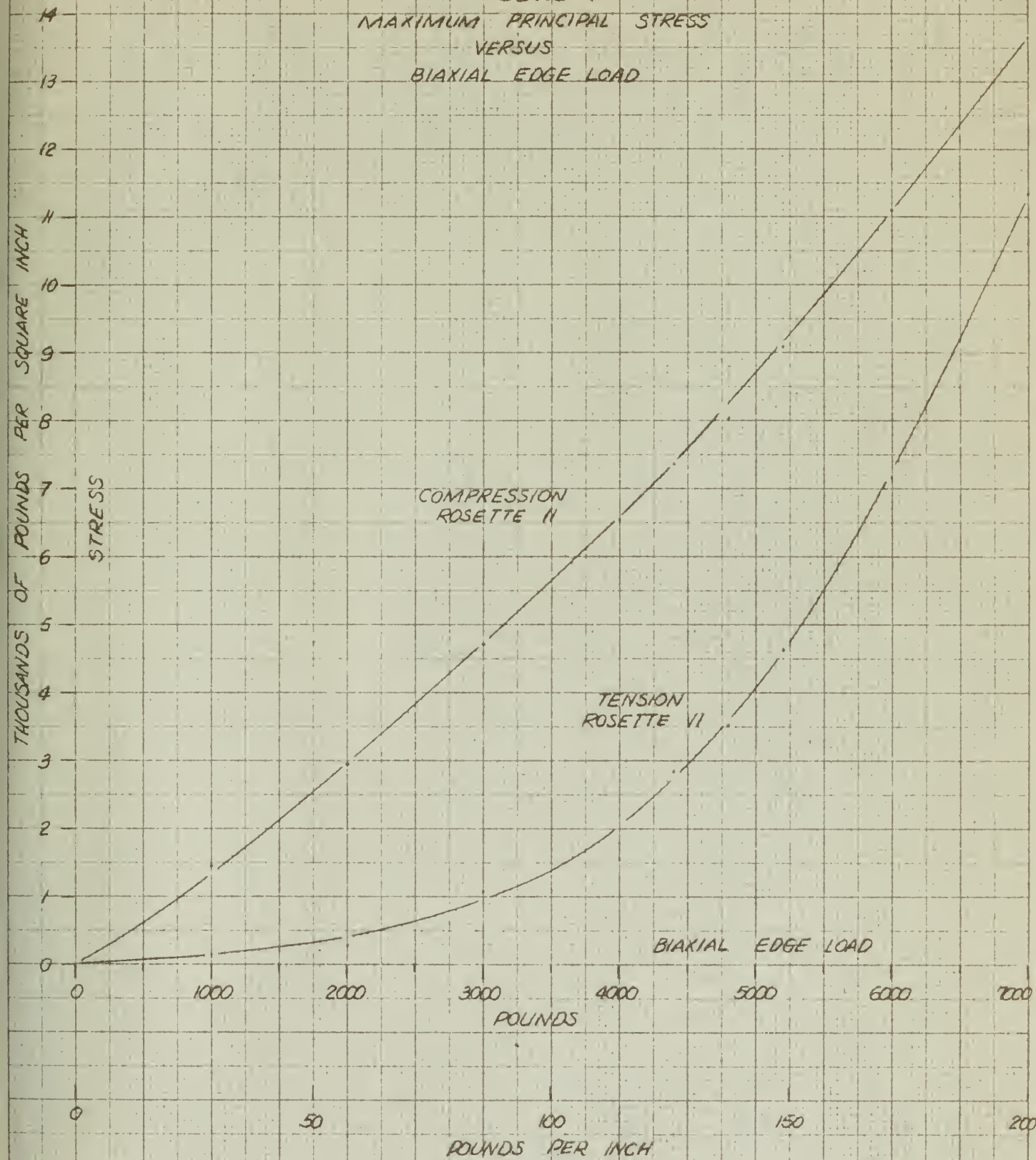


FIGURE 7
MAXIMUM PRINCIPAL STRESS
VERSUS
BIAXIAL EDGE LOAD



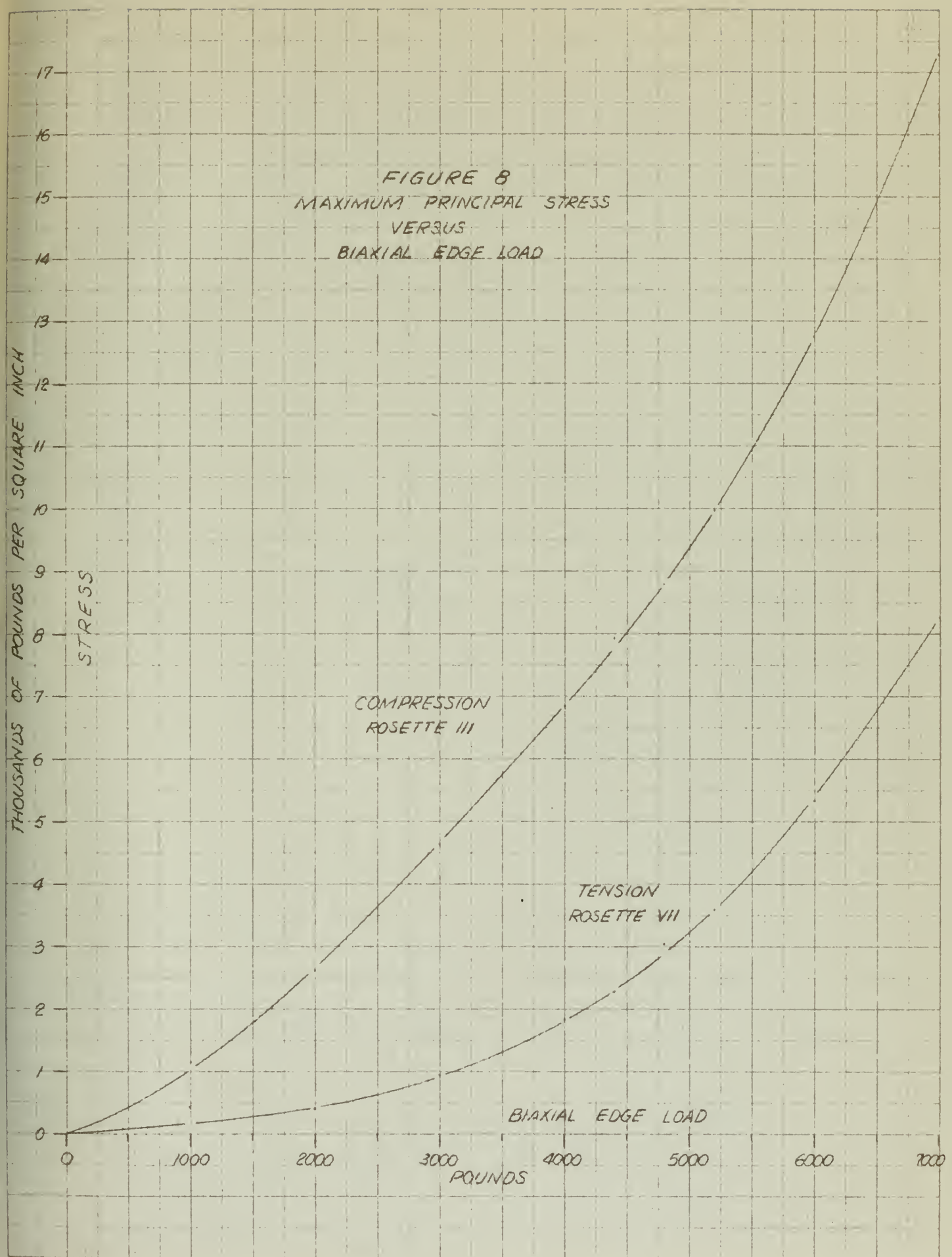


FIGURE 9
MAXIMUM PRINCIPAL STRESS
VERSUS
BIAXIAL EDGE LOAD

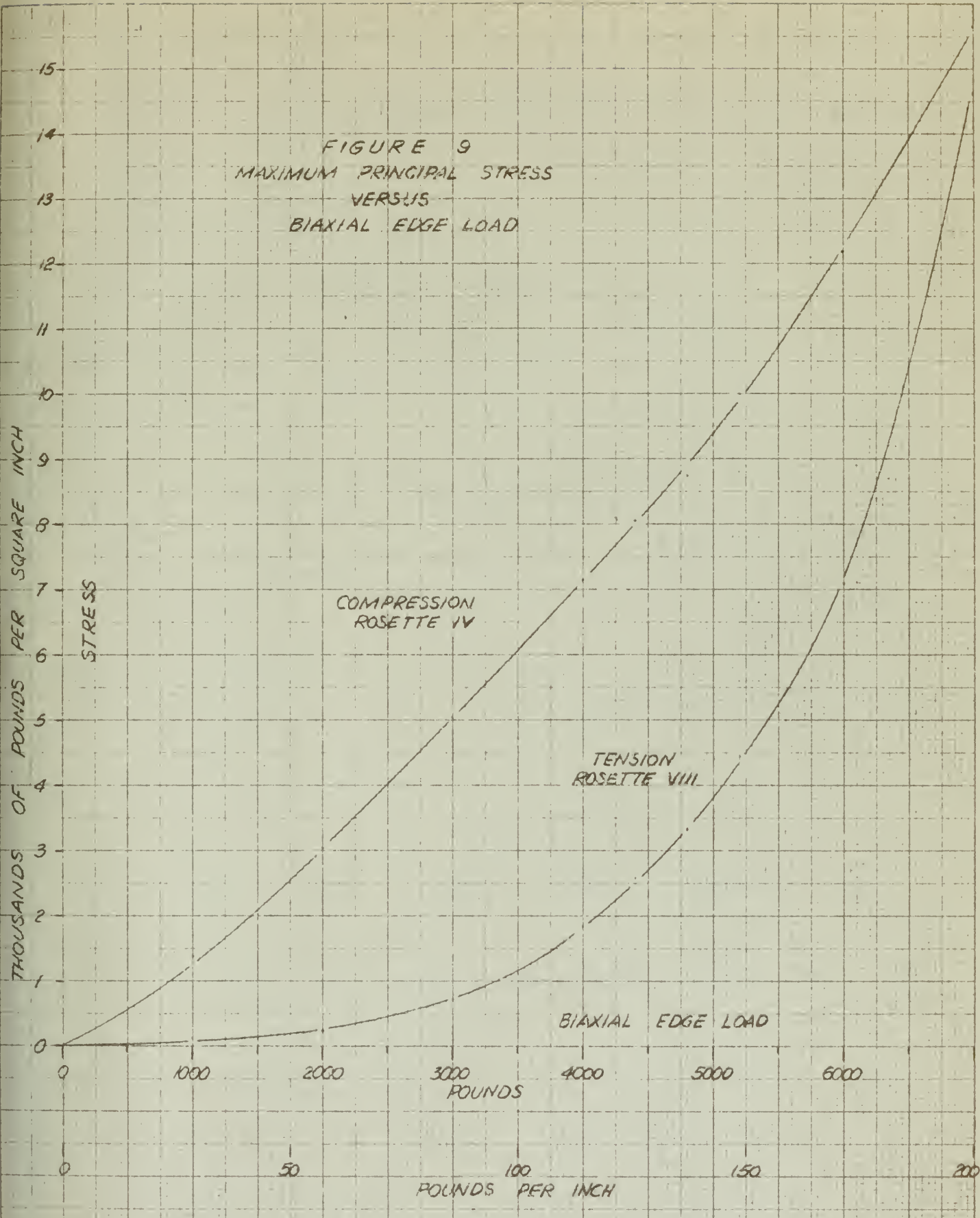
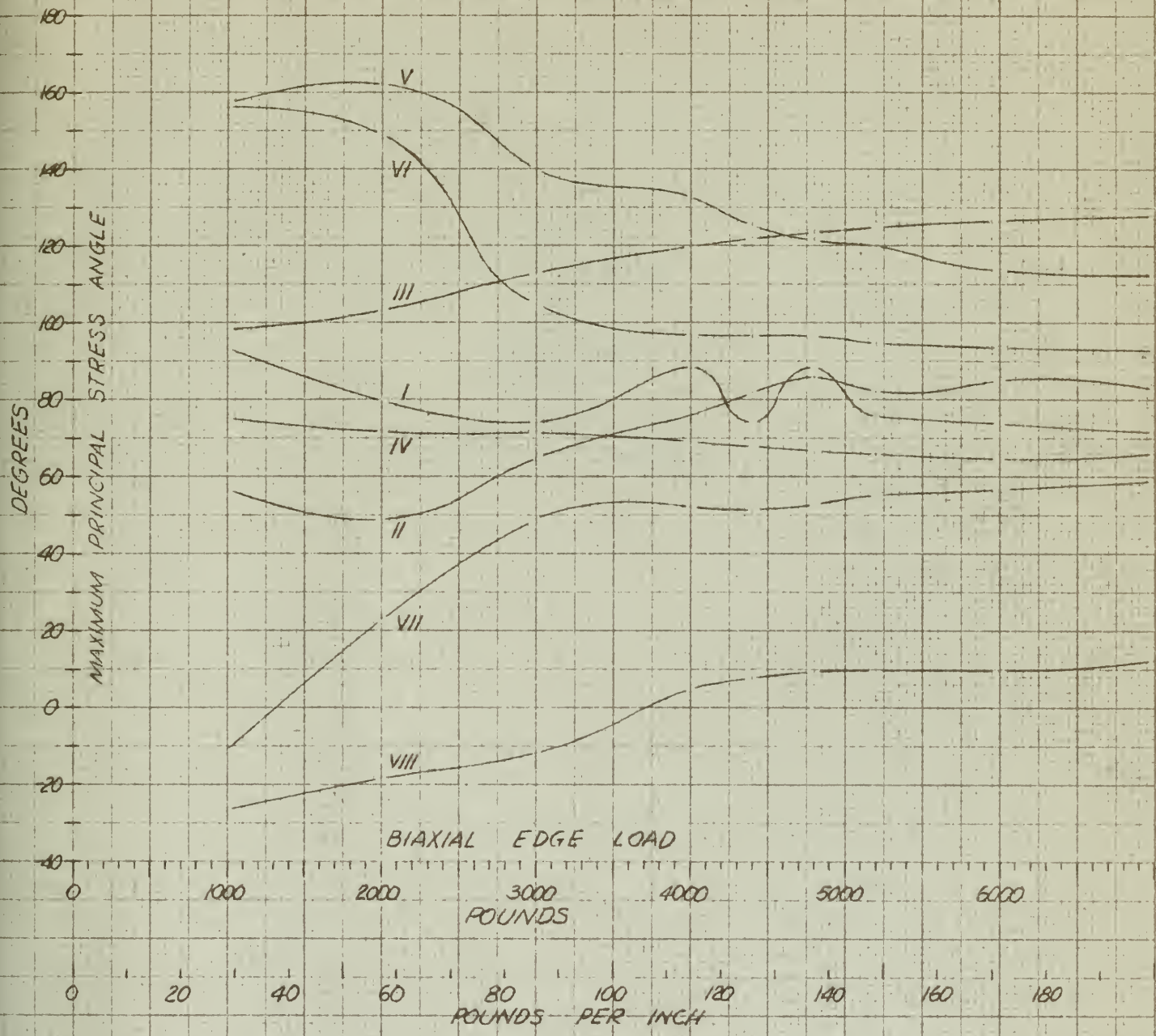


FIGURE 10
MAXIMUM PRINCIPAL STRESS ANGLE VERSUS BIAXIAL EDGE LOAD



APPENDIX A
TESTING APPARATUS
FOR
THIN PLATES
SUBJECTED TO
BIAXIAL LOADING
IN THE
PLANE OF THE PLATE
EDGES SIMPLY SUPPORTED

APPENDIX A

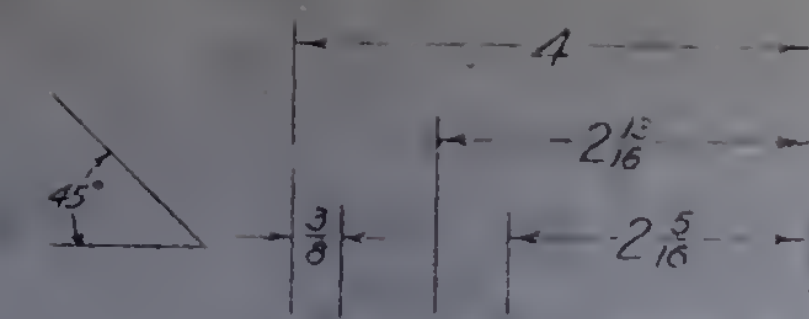
TESTING APPARATUS FOR THIN PLATES SUBJECTED TO BIAXIAL LOADING IN THE PLANE OF THE PLATE WITH ITS EDGES SIMPLY SUPPORTED

In an effort to achieve a device by which a thin plate could be subjected to biaxial loading in the plane of the plate with its edges simply supported, a frame and system of loading bars and blocks was designed. The frame (Figure 1) consists of a double picture frame of four by four by three-eighths inch structural steel. The two frames are separated at the desired distance by the proper length of pipe placed between the frames at a hole at each of the four corners; through the holes in the pipes and frames are bolts with nuts to hold the frames together firmly. This composite frame is to stand upright on supports on the bed of a compression loading machine. In the vertical direction the load is applied from the head and bed of the machine to the plate through a system of load-distributing bars and blocks (Figure 2) which distribute the load uniformly along the two horizontal edges of the plate; in the horizontal direction the load is applied to the vertical edges of the plate by two tension rods which apply the load through a similar system of load-distributing bars and blocks. The load-distributing bars are separated in their direction of applied load by lengths of one-quarter inch drill rod, and are positioned spacewise by a lightweight frame (Figure 5) with pipes and bolts. Along each side of, and adjacent to the plate are eight pairs of mated blocks (Figure 3a and 3b); they are held together by the proper length

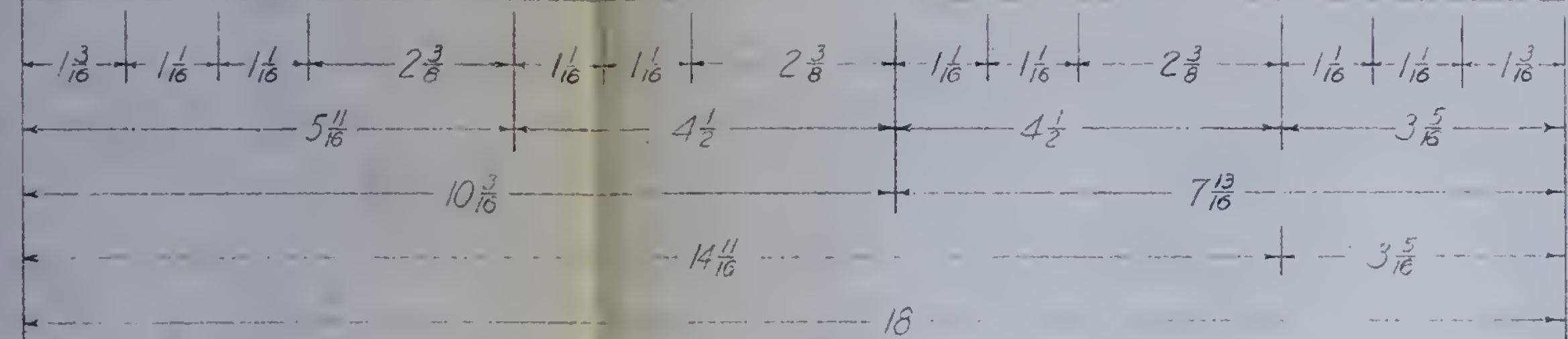
of one-quarter inch drill rod. The load-side block of each pair is held in place by six bolts threaded through the angle frames (three bolts through each frame per block) in a manner such that movement of the blocks is possible only in the plane of the plate and applied load; there are ninety-six of these bolts in each frame. The plate-side block of each mated pair is toothed in order that the restraint imposed on the compression of the edge of the plate when subjected to load will be minimized.

This design allows for rotation of the edges of the plate about lines in the extended middle plane of the plate and for translation of the edges of the plate in planes parallel to the middle plane of the plate. The assembly will accommodate one size plate, a thirty-six inch square test specimen. It allows for an edge translation of approximately three-sixteenths of an inch, for an edge rotation of approximately fifteen degrees and/or a deflection at the center of the plate of approximately two inches for a one inch thick plate. For plates thinner than one inch the allowable deflection at the center increases by one-half the amount that the plate is less than one inch thick.

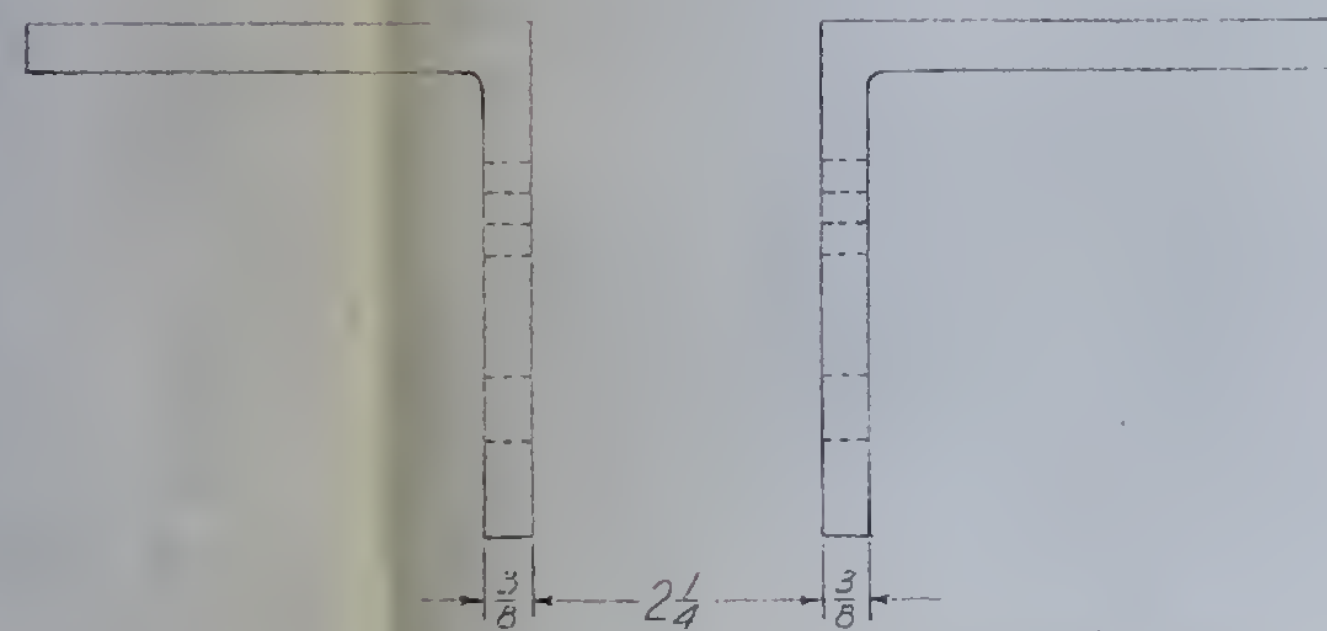
For plates of thickness in the order of one-half inch or less, it is necessary to modify the arrangement in that at comparatively small loads the test specimen is unstable with respect to the toothed loading blocks and will spring free of the teeth. By reducing the size of the plate and installing restraining blocks (Figure 6) this difficulty is eliminated.



Ninety six holes each frame tapped for
 $\frac{1}{4}$ inch USS cap screws



Double picture frame of 4 by 4 by $\frac{3}{8}$ inch structural
 steel angle separated at each corner by a
 $2\frac{1}{4}$ inch length of $\frac{5}{8}$ inch pipe and held together
 by a $3\frac{1}{2}$ by $\frac{1}{2}$ inch bolt with nut through each
 pipe and angles



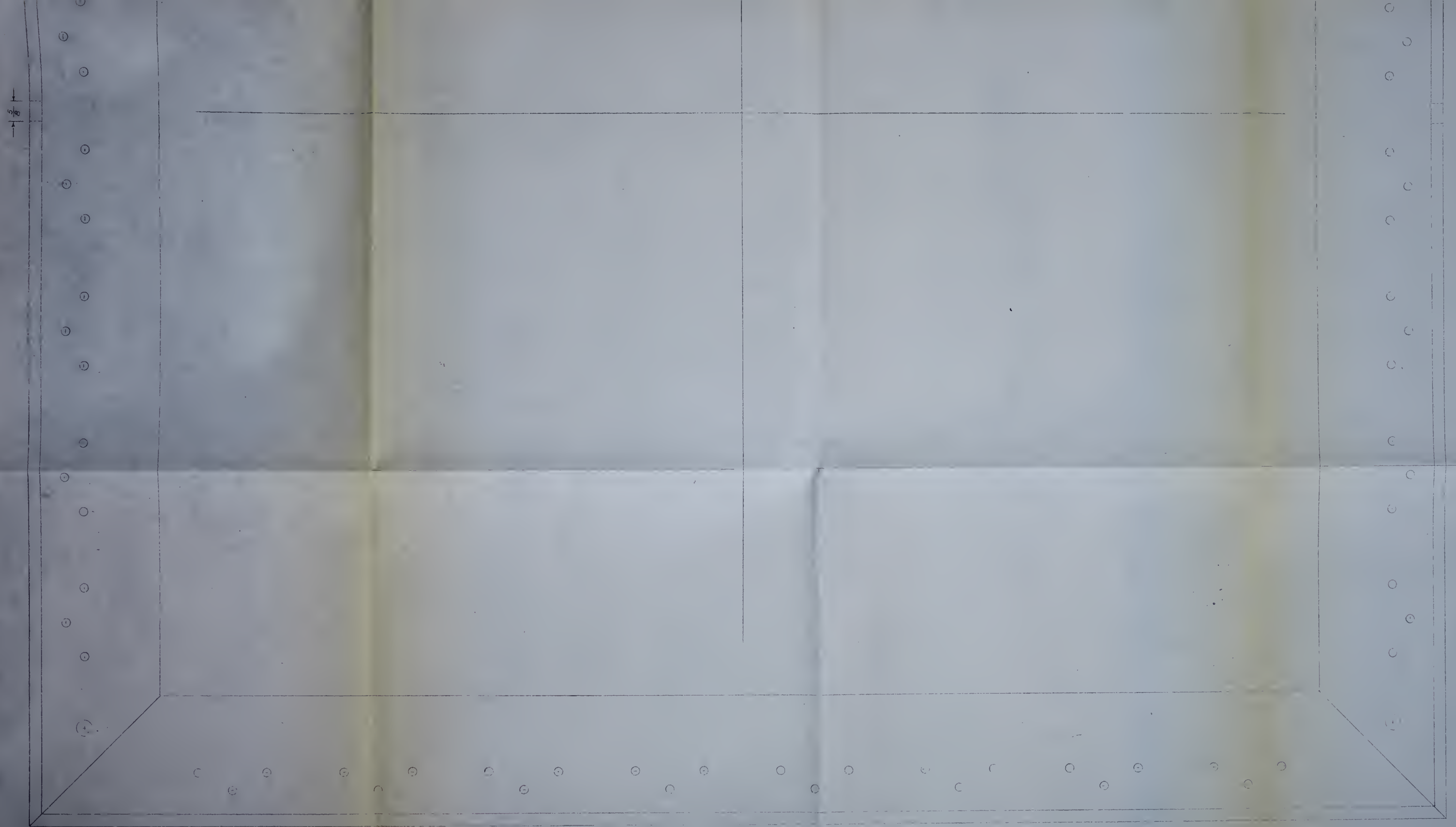
Cross Section
 At Mid-Span
 Of Uppermost Two Angles

DISTANCES TO BE MEASURED
 FROM THIS CENTER LINE

LAYOUT OF ANGLE FRAMES

DIMENSIONS : Inches
 SCALE : Half Size

$\frac{5}{8}$



2-1-22

1-1-11

1-1-11

at each end
bearing 1" from margin of frame
(as shown in layout)
for metal blocks
at each end

LAYOUT
OF
LOADING BARS AND BLOCKS

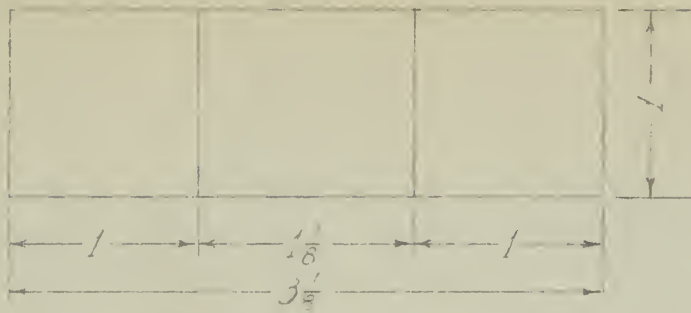
DIMENSIONS : Inches
SCALE : Half Size
MATERIAL : Soft Mild Steel

3-204

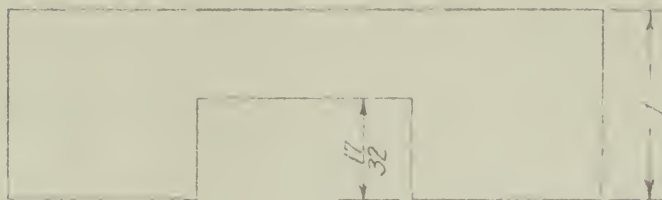
MATERIAL : CARBON STEEL

Cross Section
of
Bars and Blocks
for
Horizontal Loading

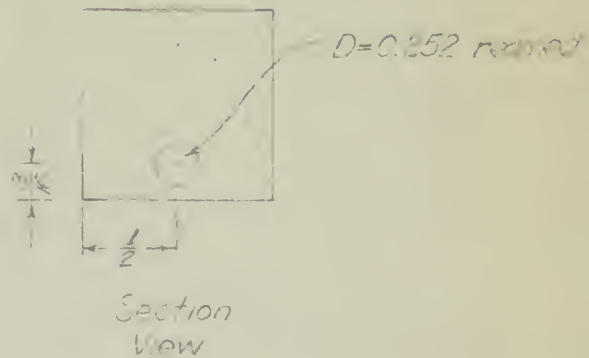
OUTER HINGED BLOCK



Bottom Plan View



Elevation View



Section View



Top Plan View

Each pair of mated blocks connected by $4\frac{3}{8}$ inch length of one-quarter inch drill rod

This block and toothed block to which it mates are to be cut to dimensions such that a standard fit is obtained at contact surfaces

DIMENSIONS: Inches

SCALE: Full Size

MATERIAL: Cold Rolled Steel

DESIGNED BY: GAR

CHECKED BY: JAW

APPROVED BY: JDA

INNER TOOTHED HINGED BLOCK



Top Plan View



Elevation View



Bottom Plan View

DIMENSIONS: inches

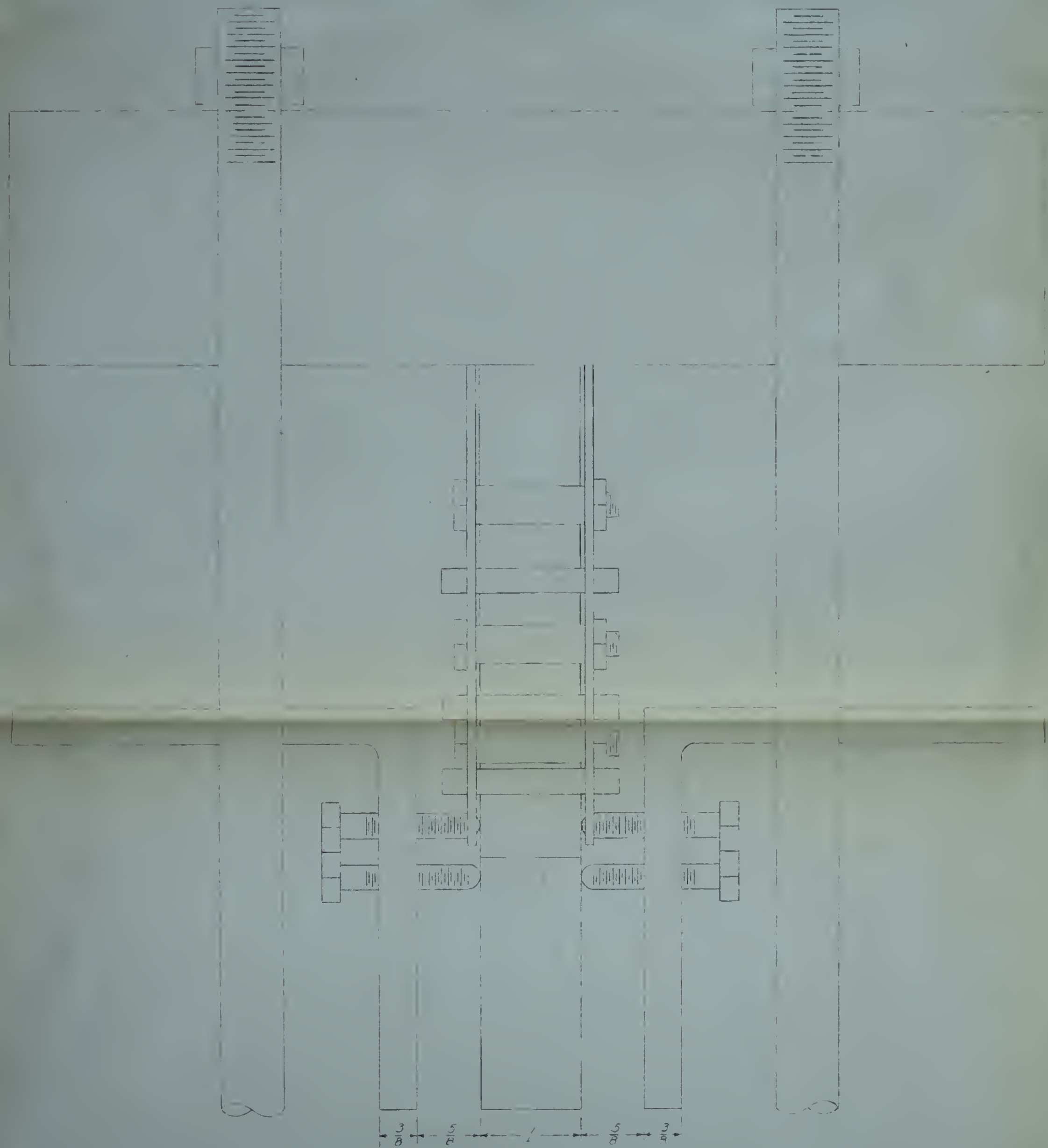
SCALE: 2 in. = 1 in.

MATERIAL: Cold Rolled Steel

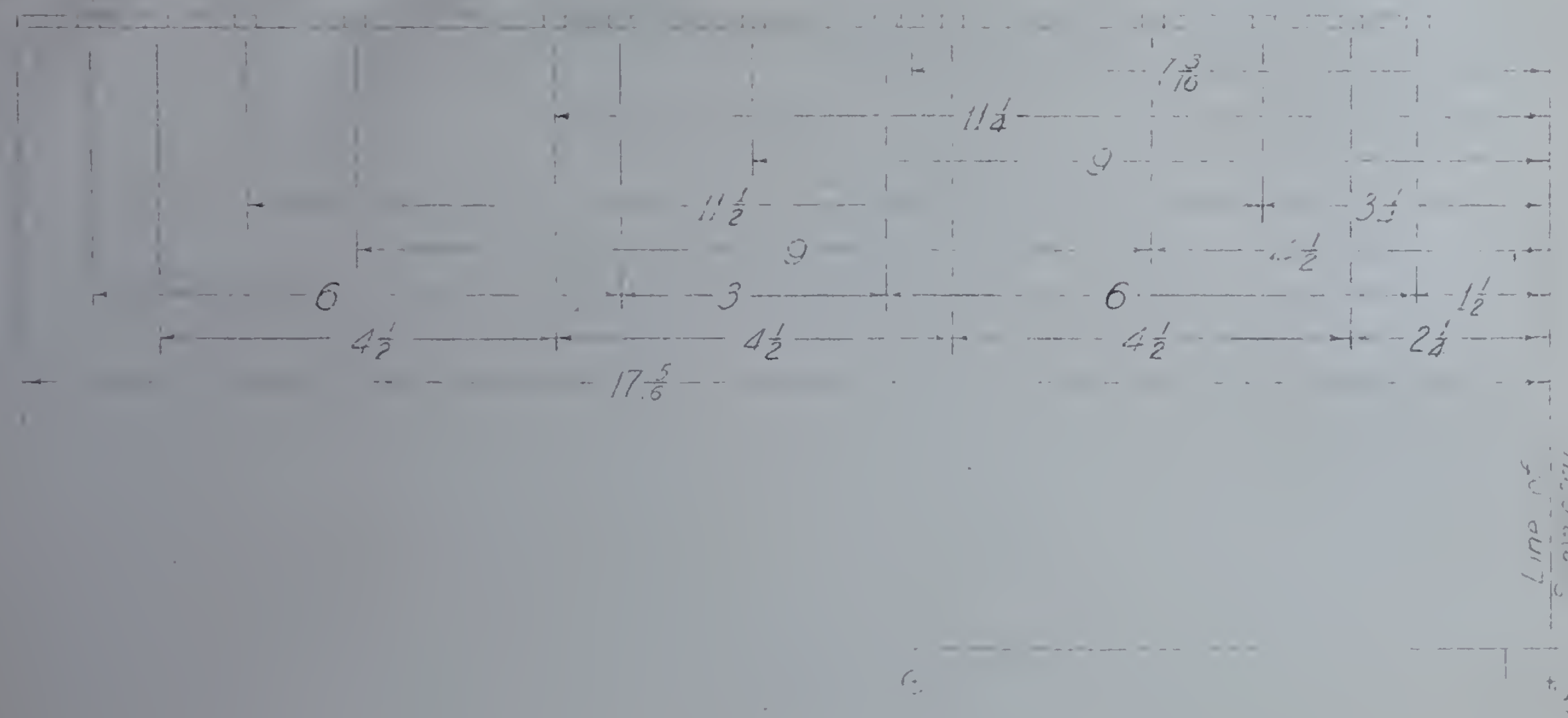
DESIGNED BY: GAR

CHECKED BY: JAW

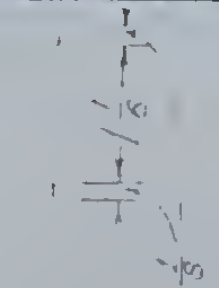
APPROVED BY: JAW



Cross Section
A1
Mid-Span of Testing Frame
Illustrating
Horizontal Loading Arrangement



Two $\frac{1}{8}$ inch thick plates of positioning frame are mounted by means of $1\frac{1}{8}$ inch lengths of $\frac{5}{16}$ inch pipe located at $\frac{1}{2}$ inch on the holes which are $\frac{1}{2}$ inch by $\frac{1}{4}$ inch. The positioning pipe screw, which is $\frac{1}{2}$ inch long, and will hold for $1\frac{3}{4}$ inch by $\frac{1}{4}$ inch will hold for 1 inch roller.



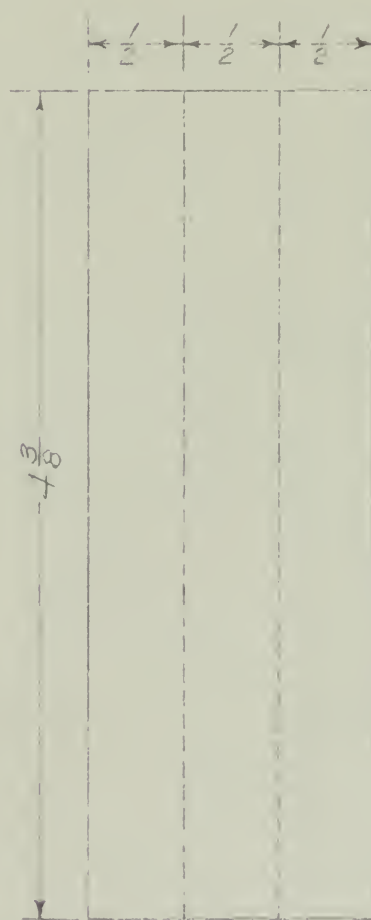
DIMENSIONS: Inches
SCALE: Full Size
MATERIAL: Steel

Layout of Positioning Frame for Lifting Bars and rollers

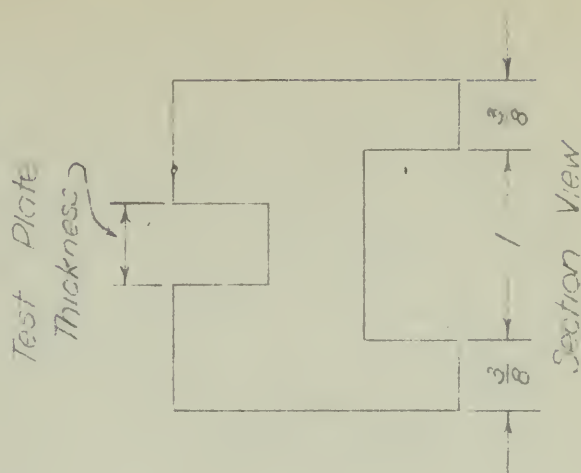
PLATE POSITIONING BLOCK



Plan View



Elevation View



Section View

DIMENSIONS : Inches
SCALE : Full Size
MATERIAL : Birch

GAP 1940

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The behavior of a
metalite plate when
subjected to uniformly
distributed loads
acting in the plane
of the plate.

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The behavior of a
metalite plate when
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